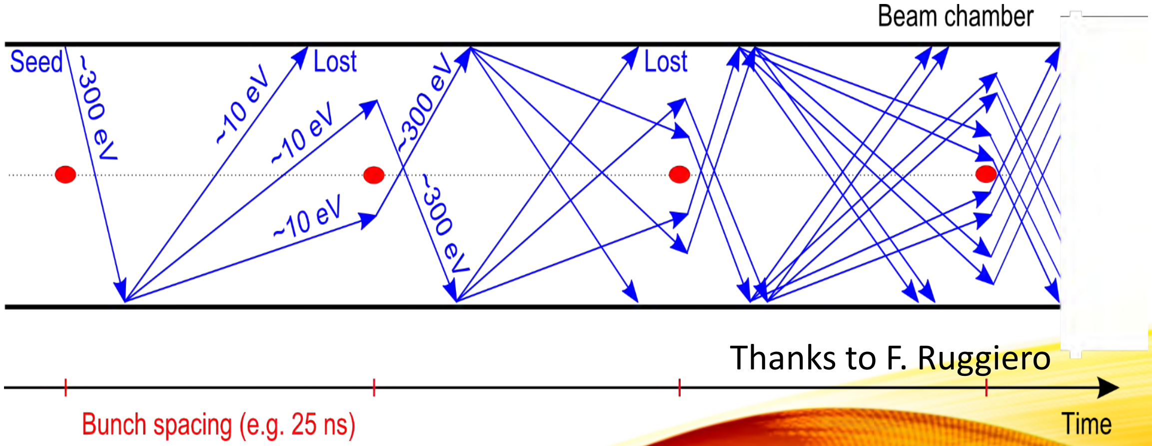
STRATEGIES FOR ELECTRON CLOUD MITIGATION AT FUTURE ACCELERATORS

R. Cimino LNF-INFN



OUTLINE

- Introduction
- e$^-$cloud mitigation methods in a global scenario: compatibility with impedance, vacuum, etc.
- Few examples: LASE/LESS – low SEY coatings (a-C)
- Conclusions

INTRODUCTION

The performance reach of accelerators crucially depends on the **vacuum system**

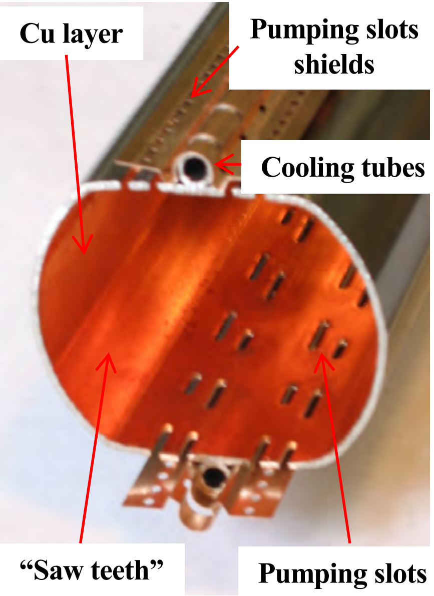
1. The beam interacts with **the rest gas in the vacuum chamber** causing:
   - **reduced beam lifetime** - and/or **emittance growth** - trigger **avalanche** multiplication processes

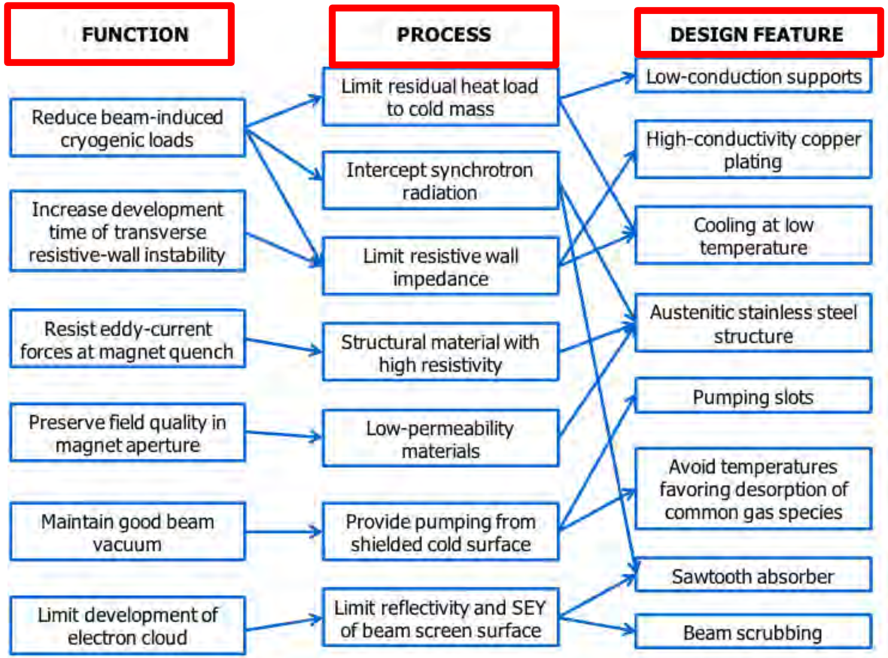
2. The **vacuum system** plays an important role for beam stability:
   - Its material(s) conductivity, shape, coating mainly determine **resistive wall impedance** of a machine
   - Transitions between pipes, bellows, etc. significantly contribute to the **global machine impedance**
   - Total impedance needs to be kept below a certain **budget** to allow operation at the desired intensity.

3. The **vacuum chamber** also affects beam stability and lifetime otherwise
   - Its inner wall surface properties in particular **desorption and electron yields**, are critical
   - High desorption yields can lead to **pressure runaway**
   - High electron yields can lead to **electron cloud formation**
   - Distributed pumping from surface/design (e.g. NEG coating, pumping holes)
   - Shape optimisation for photon absorption (antechambers, slits)

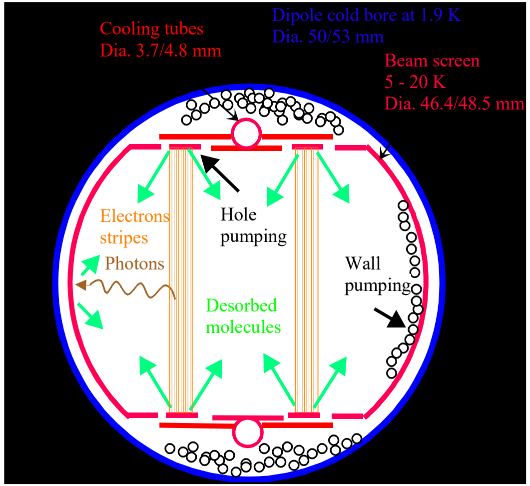
A complex **Functional diagram** (here shown for the **BS of LHC**) must be fulfilled.

LHC Beam Screen (BS)





V. Baglin et al. CERN-ATS-2013-006



e⁻ cloud control and mitigation is one (important) aspect in a much more general scenario.

e^- CLOUD FORMATION

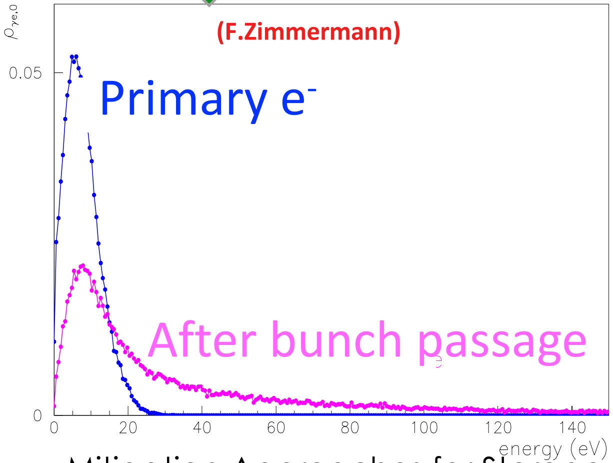
Generation of electrons inside the vacuum chamber (primary, or seed, electrons)

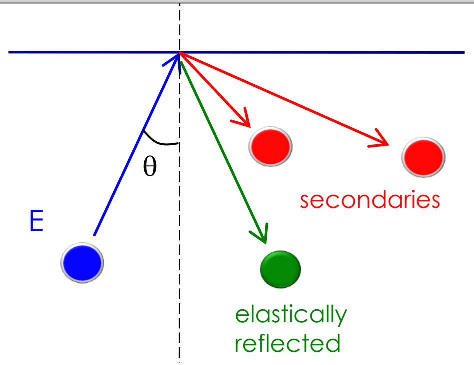
- Residual gas ionization
- Photoelectrons from synchrotron radiation
- Desorption from the losses on the wall

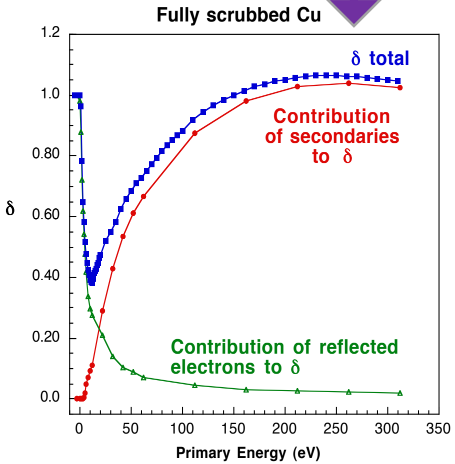
e^- CLOUD FORMATION

Generation of electrons inside the vacuum chamber (primary, or seed, electrons)

- **Acceleration of primary electrons in the beam field**
- **Secondary electron production when hitting the wall**





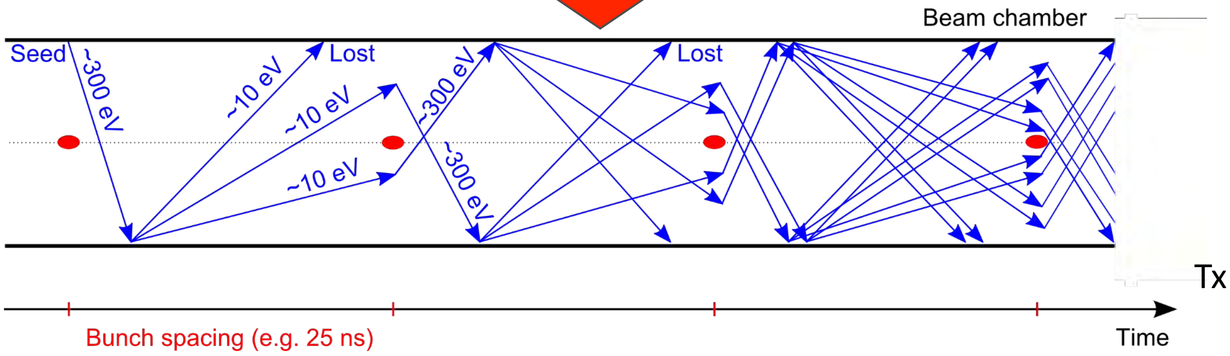


R. Cimino et al *PRL* 2004

e⁻ CLOUD FORMATION

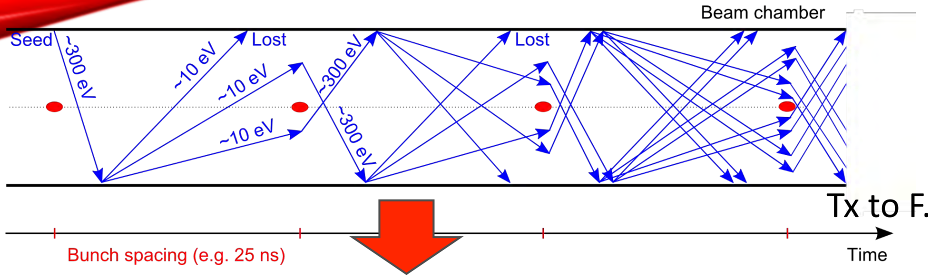
Generation of electrons inside the vacuum chamber
(primary, or seed, electrons)

- Acceleration of primary electrons in the beam field
- Secondary electron production when hitting the wall
- Avalanche electron multiplication



Tx to F. Ruggiero

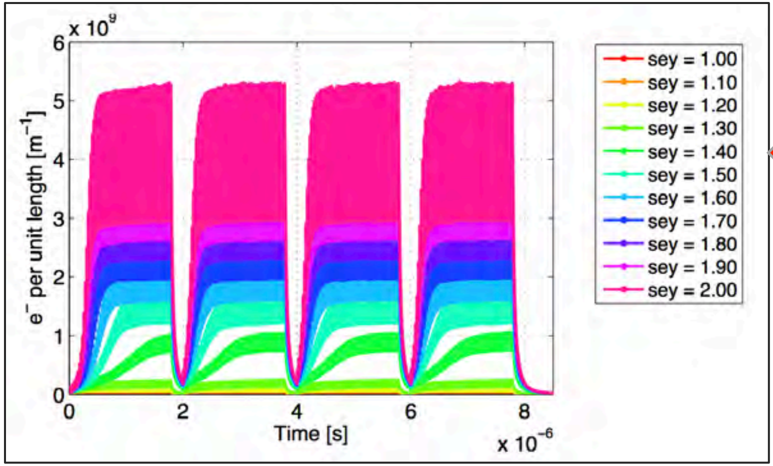
e⁻ CLOUD FORMATION



Tx to F. Ruggiero

After the passage of several bunches, the electron distribution inside the chamber reaches a stationary state (electron cloud)

Tx to G. Rumolo



The **presence** of an e⁻cloud inside an accelerator has consequences on the **machine** (pressure rise, outgassing, heat load, etc.) and on the **beam** (Coherent instability, both single and multi-bunch driven, emittance growth, luminosity and Energy loss, etc.). **Needs to be mitigated!**

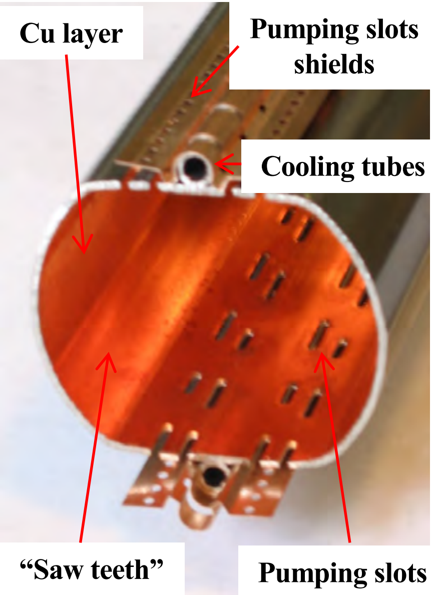
Existing and planned accelerator machines base the reaching of their design parameters to the capability of obtaining walls with a SEY ~1.1 or below!

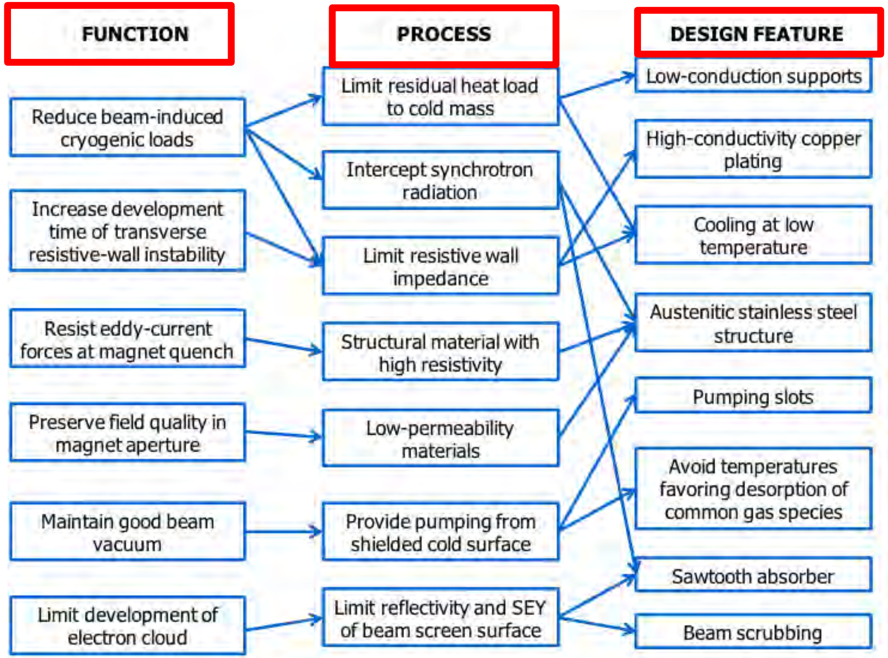
Mitigation Strategies

Active elements	External solenoid field	Electrodes in the lattice
Surface modification	Geometrical modifications	Intrinsically low SEY material
Machine operation	Electron and/or photon Scrubbing	Run with low e^- cloud filling partners

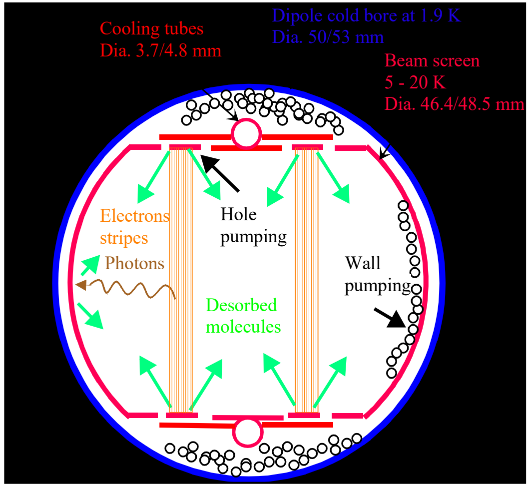
The global scenario: e^{-} cloud methods must be compliant with all BS features.

For LHC:





V. Baglin et al. CERN-ATS-2013-006



Mitigation Strategies

	Issues:
External solenoid field	Costly and not always applicable
Electrodes in the lattice	Costly, not always applicable, impedance?
e^- and/or Ph. Scrubbing	Time consuming, not stable and “asymptotic”
Run with low e^- cloud filling partners	Costs machine performance (reduced n. of bunches)
Geometrical modifications	Impedance, dust, vacuum behavior.
Intrinsically low SEY material	Impedance, stability, adhesion, etc

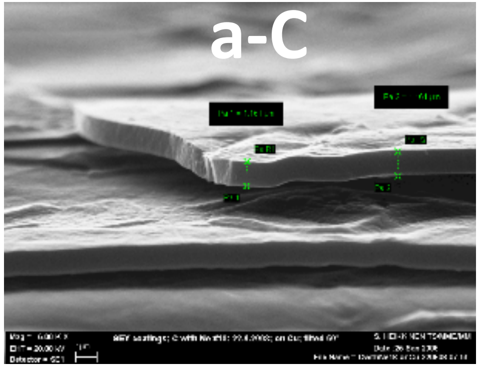
Mitigation Strategies

NEGs, a-C

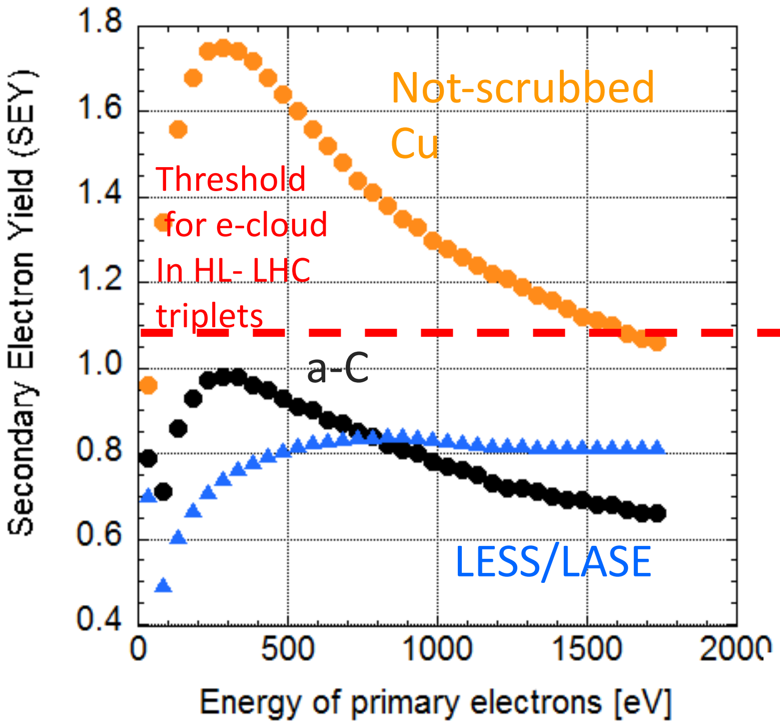
Intrinsically low SEY material

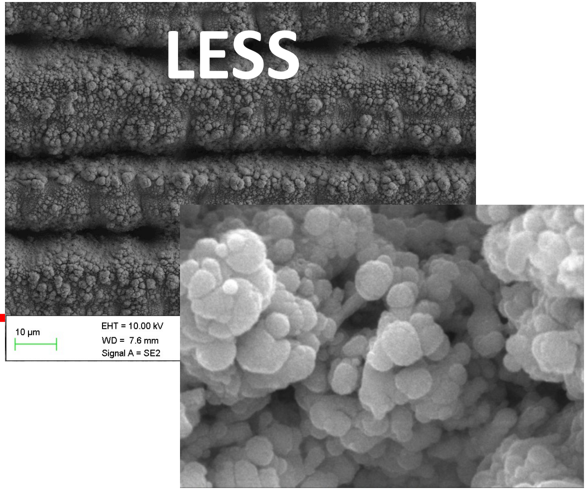
Geometrical modifications

- Nano - LASE/LESS



Low SEY results from the electronic properties





Low SEY is a morphological effect

Tx to Pedro Costa Pinto

But, within the global context:

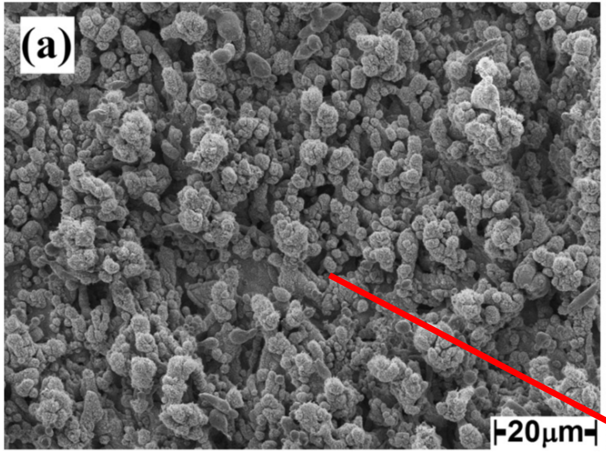
Mitigation Strategies

Issues:

Mitigation Strategies	Issues
External solenoid field	Costly and not always possible
Electrodes in the lattice	Costly, not always possible, impedence?
Machine Scrubbing	Time consuming, not stable and "asymptotic"
Run with low e$^-$ cloud filling partners	Costs machine performance (reduced n. of bunches)
Geometrical modifications	**Impedance**, **dust**, **vacuum behavior….**
Intrinsically low SEY material	**Impedance**, stability, adhesion, etc

Limiting SEY with **LASE/LESS -Cu**

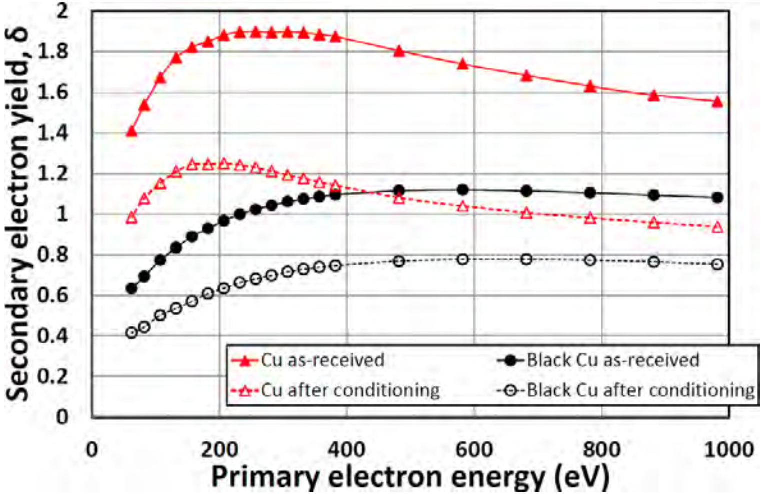
surface morphology of LASE/LESS



R. Valizadeh et al. , Appl. Surf. Sci. (2017)

Very low SEY

R. Valizadeh et al. , Appl. Phys. Lett. (2014)



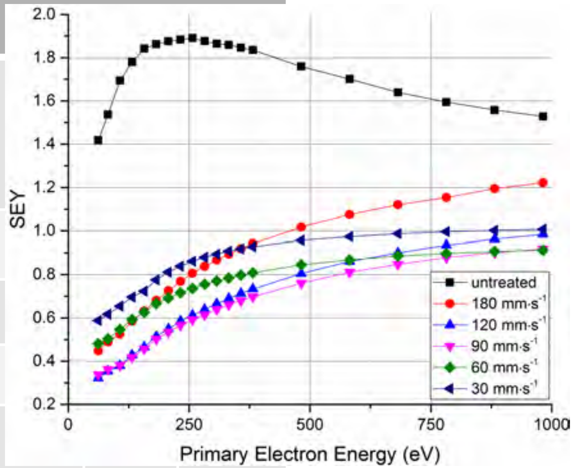
R. Valizadeh, et al. Appl. Phys. Lett. 105, 231605 (2014)

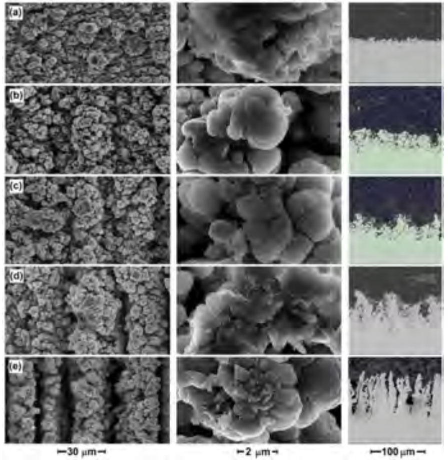
The structure is expected to have higher **impedance** (by construction), to be prone of producing **dust** during formation and to have a much augmented **vacuum** surface

Ongoing LASE/LESS-Cu Impedance studies

See: O. Malyshev et al. e-cloud 2018 Proceeding (2020); R. Valizadeh, et al. Appl. Phys. Lett. 105, 231605 (2014)

Sample	Scan speed [mm/s]	Groove depth [μm]	R_s [Ω] average
Cu	untreated	-	0.033
(a)	180	8	0.078
(b)	120	20	0.13
(c)	90	35	0.14
(d)	60	60	–
(e)	30	100	





SEY and surface resistivity strongly depend on LASE structure (presence groove directions)

Ongoing LASE/LESS-Cu Impedance studies

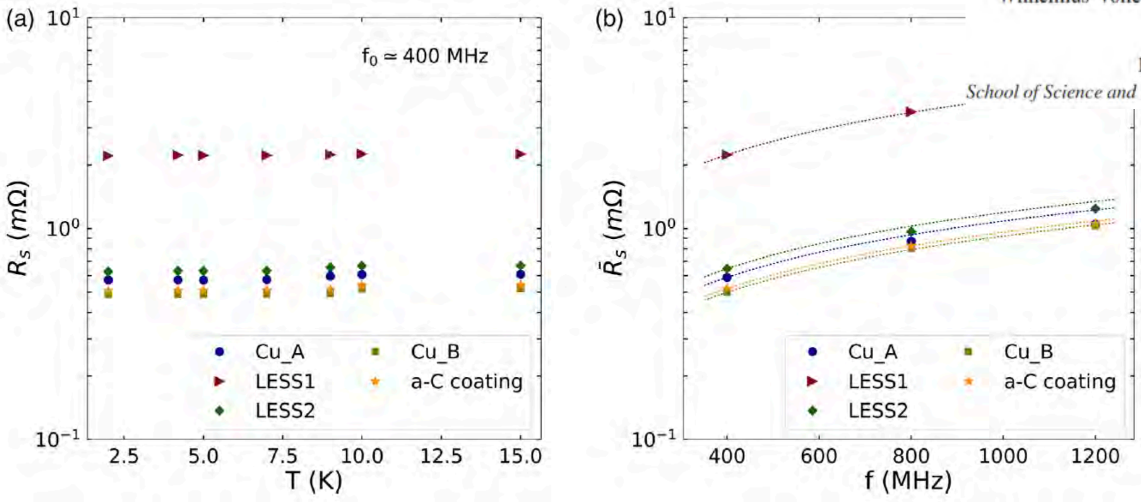
PHYSICAL REVIEW ACCELERATORS AND BEAMS **22**, 063101 (2019)

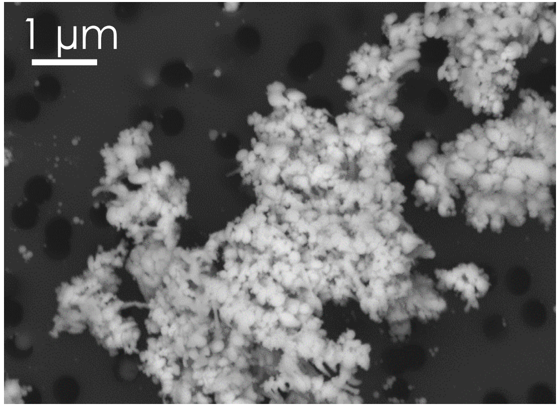
Cryogenic surface resistance of copper: Investigation of the impact of surface treatments for secondary electron yield reduction

Sergio Calatroni,* Marco Arzeo, Sarah Aull, Marcel Himmerlich, Pedro Costa Pinto, Wilhelmus Vollenberg, Beniamino Di Girolamo, Paul Cruikshank, and Paolo Chiggiato
CERN, CH-1211 Geneva 23, Switzerland

David Bajek, Stefan Wackerow, and Amin Abdolvand
School of Science and Engineering, University of Dundee, Dundee DD1 4HN, Scotland, United Kingdom

Optimization is in progress!





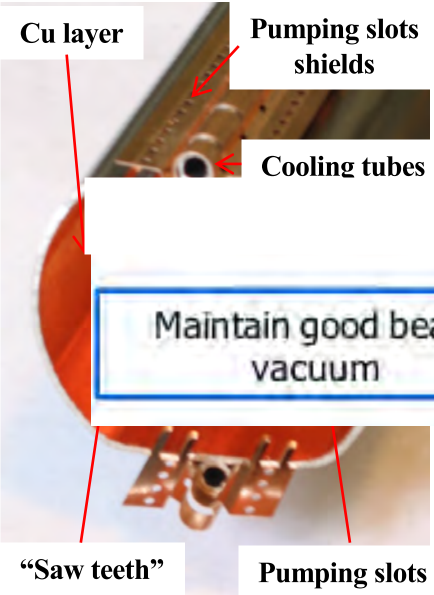
Dust production is still an open issue

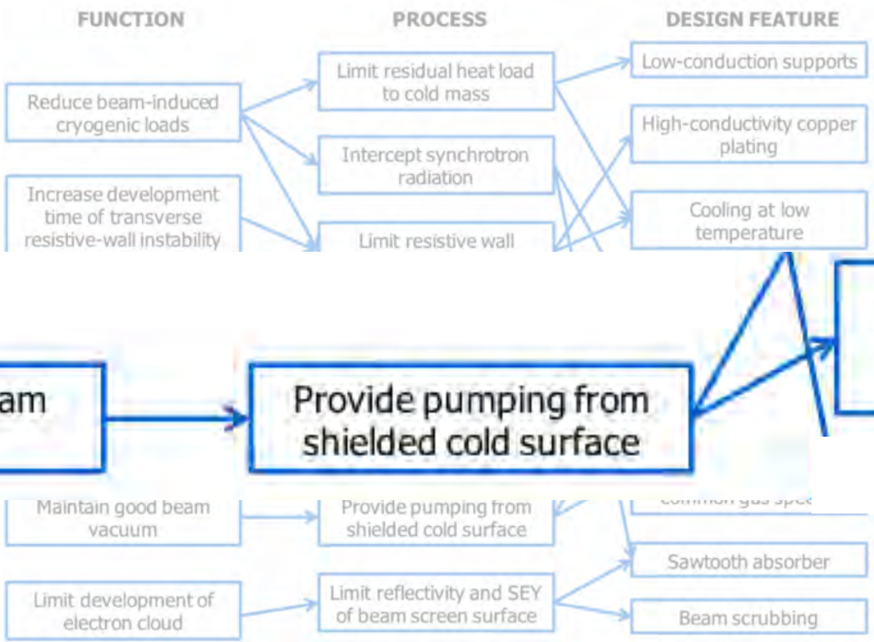
Collected particles after Ultrasounds cleaning

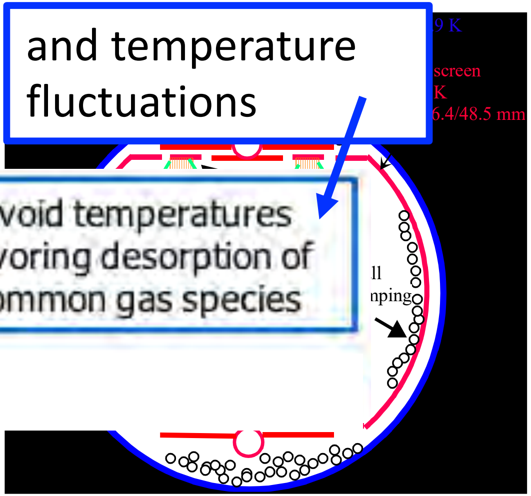
LASE/LESS and Vacuum issues

(Does the augmented surface and structure affect vacuum properties?)

For LHC:







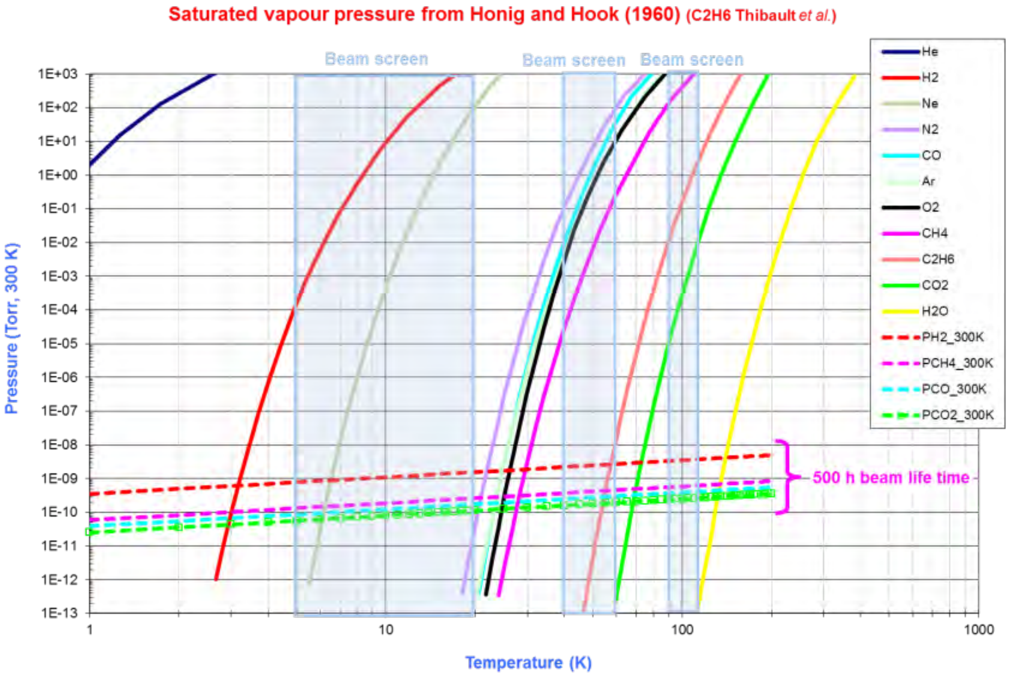
V. Baglin et al. CERN-ATS-2013-006

WHEN OPERATING AT LOW TEMPERATURE

LHC
Synchrotron Radiation Power = 0.13 W/m
FCC
Synchrotron Radiation Power = 40 W/m

Working Pressure
($<10^{-11}$ mbar)

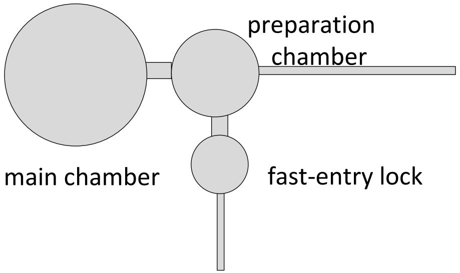
Beam screen
Temperature Range



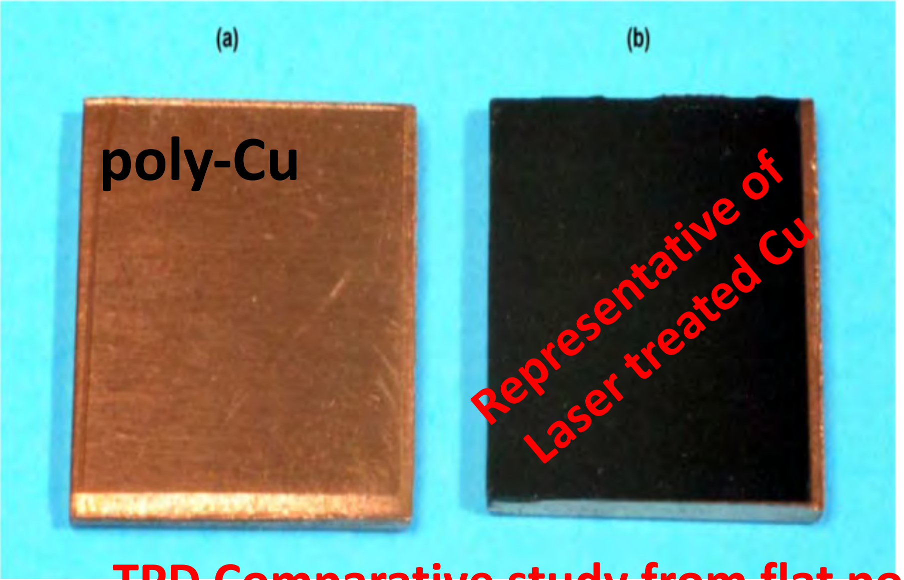
Independently on the substrate treatment, **the thermal stability against small BS T fluctuation has to be guaranteed**

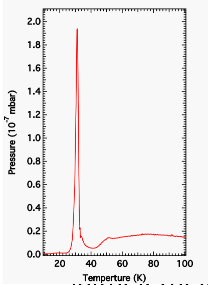
We studied thermal stability @ LNF within EuroCirCol collaboration

Ultra high vacuum systems



- LNF-cryogenic manipulator
- Sample at **15-300 K**



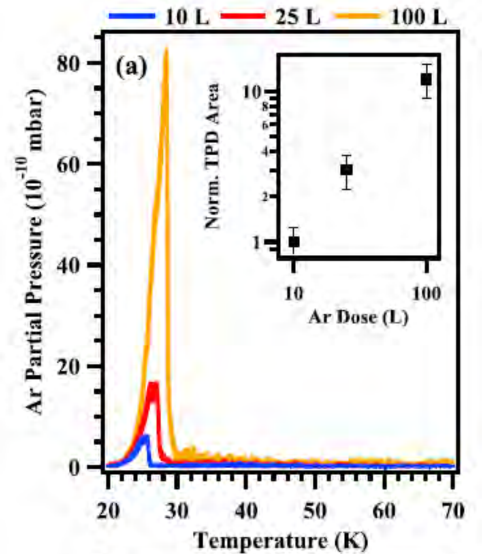


Temperature Programmed Desorption (TPD) and Mass Spectrometry measurements

QMS (Hiden HAL 101 Pic)

TPD Comparative study from flat poly-Cu and LASE-Cu unbaked samples using different gases. (Ar, CH_4, CO and H_2)

TPD from unbaked lase-Cu for temperature induced vacuum transient study: Ar



Single TPD peak at ~30 K corresponding to the desorption of a condensed thick Ar layer

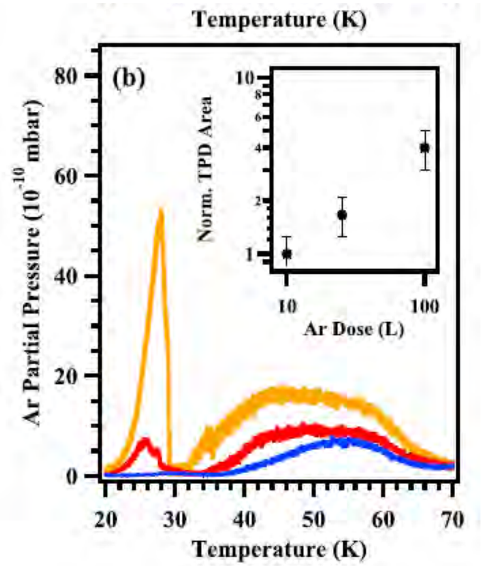
Desorption temperature determined by the weak Ar-Ar van der Waals interaction energies

Ar on poly-Cu

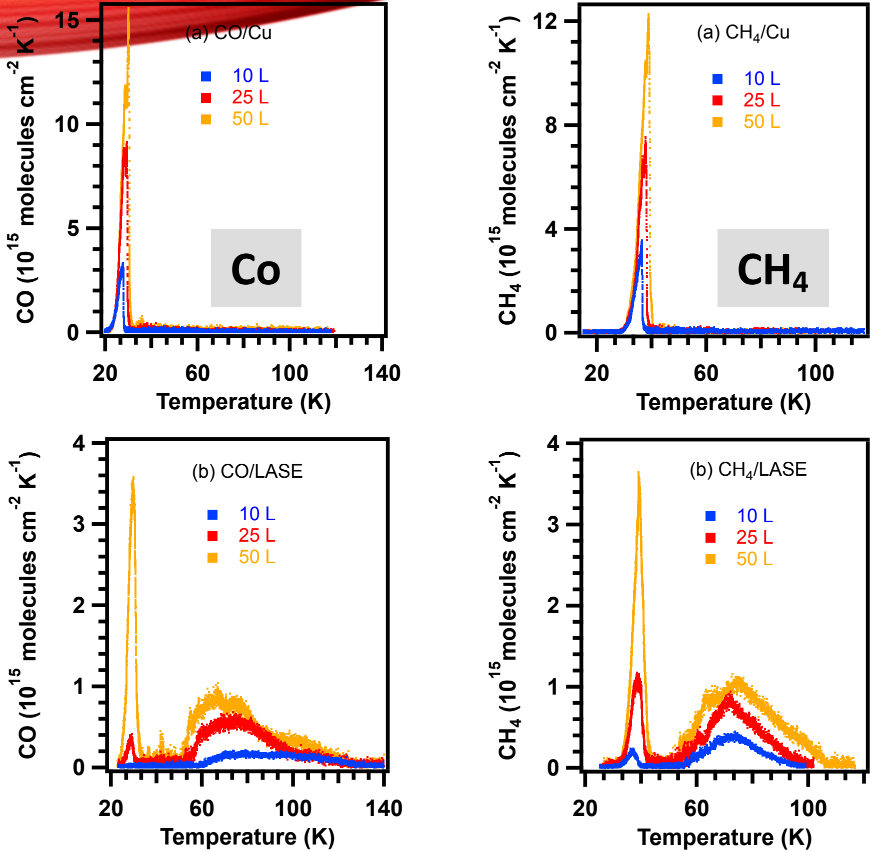
L. Spallino, M. Angelucci, R. Larciprete, R. Cimino, Appl. Phys. Lett. 114, 153103 (2019)

Ar on LASE-Cu

TPD peak at ~30 K corresponding to the desorption of a condensed thick Ar layer together with a broad TPD profiles, whose peak temperatures and widths depend on the Ar dose



TPD from unbaked lase-Cu for temperature induced vacuum transient study: CO & CH_4



L. Spallino, M. Angelucci and R. Cimino, Phy. Rev. ACC. & BEAMS 23, 063201 (2020)

Conceptually identical results have been obtained also for CO & CH_4

- For CO & CH_4 we were able to measure quantitative desorption rates (in molecules/K) to be used in gas-flow and vacuum simulations to address full vacuum compatibility vs. T fluctuations
- electron/photon stimulated desorption studies are necessary to validate/optimize LASE-Cu at low T.

Mitigation Strategies

Mitigation Strategies	Issues:
External solenoid field	Costly and not always possible
Electrodes in the lattice	Costly, not always possible, impedence?
Machine Scrubbing	Time consuming, not stable and "asymptotic"
Run with low e^- cloud filling partners	Costs machine performance (reduced n. of bunches)
Geometrical modifications	**Impedance**, dust, **vacuum behavior**.
Intrinsically low SEY material	**Impedance**, stability, adhesion, etc

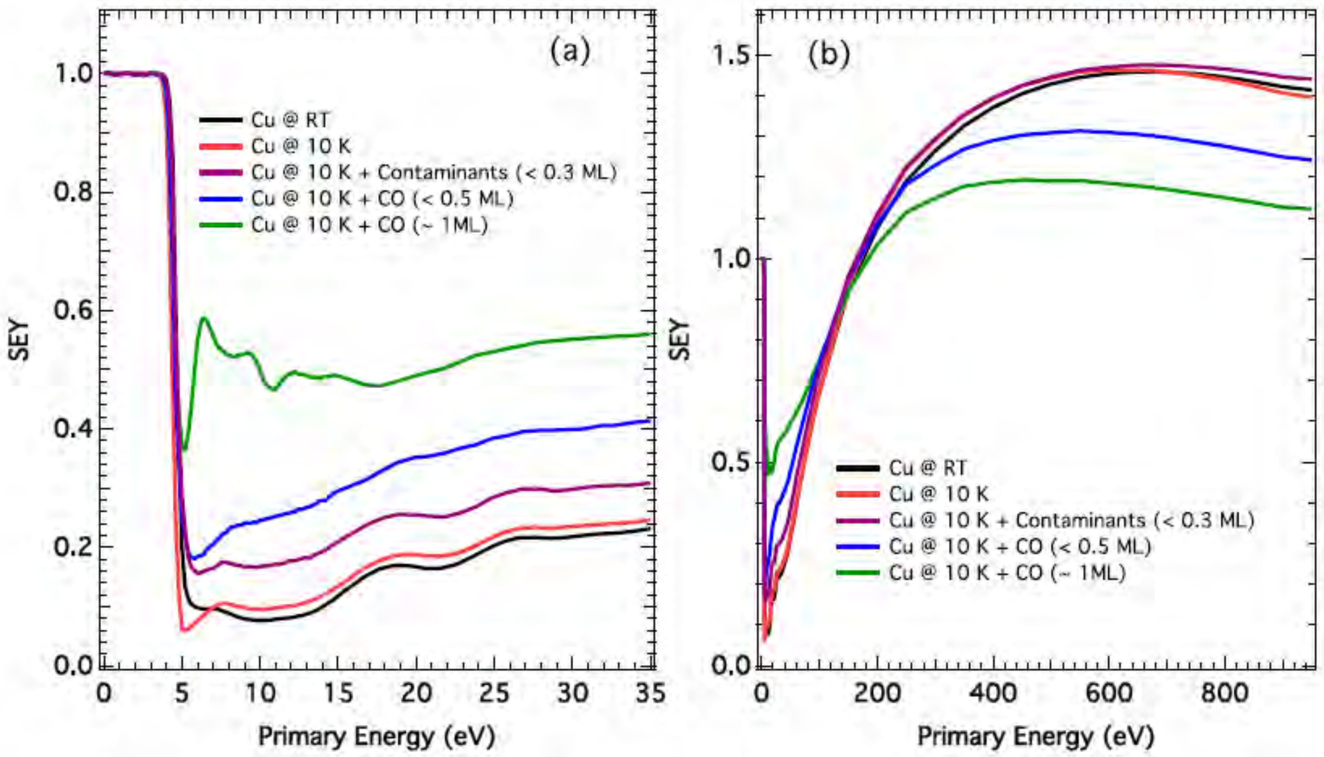
Coatings:

- Low intrinsic SEY (NEG and a-C)
- Typically high surface resistance of impact to impedance.
- We know that: - SEY is very surface sensitive

  - **Surface resistance skin depth ~ 0.1-10 μm**
- **Can the coating be thin enough to reduce SEY without affecting material surface resistance within the skin depth?**
- (Of course NEG is deposited not only to reduce SEY but its thickness grant pumping reservoir so... It is a different story!)

SEY is very surface sensitive:
at LT (20 K) small quantities of contaminants affects it!

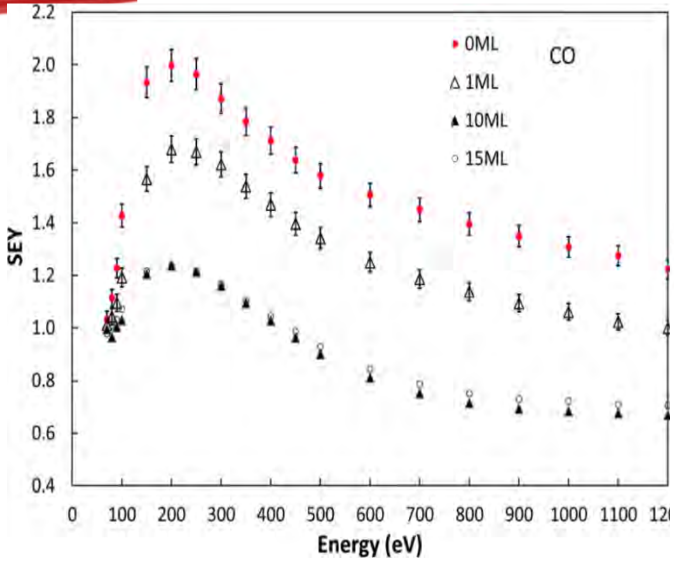
L. A. Gonzalez et al., AIP Adv. (2017)



- SEY is highly sensitive to the presence of adsorbates, **even at sub-monolayer coverages**
- SEY of cold surfaces influenced by gas physisorption

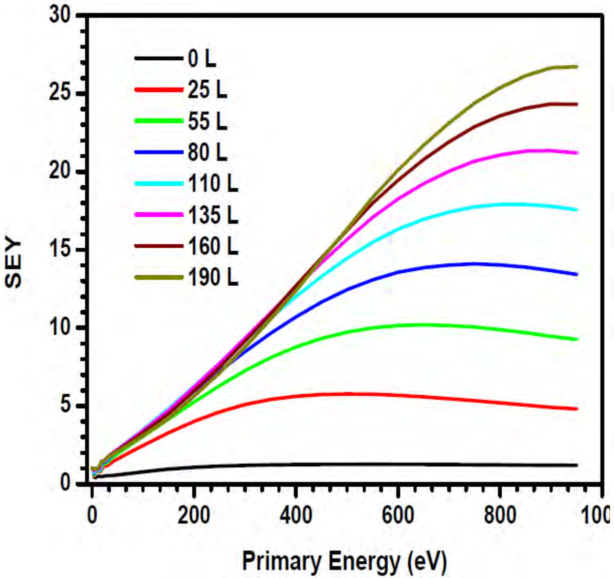
SEY Surface sensitivity: gases on LT Cu

CO thick layer coverage



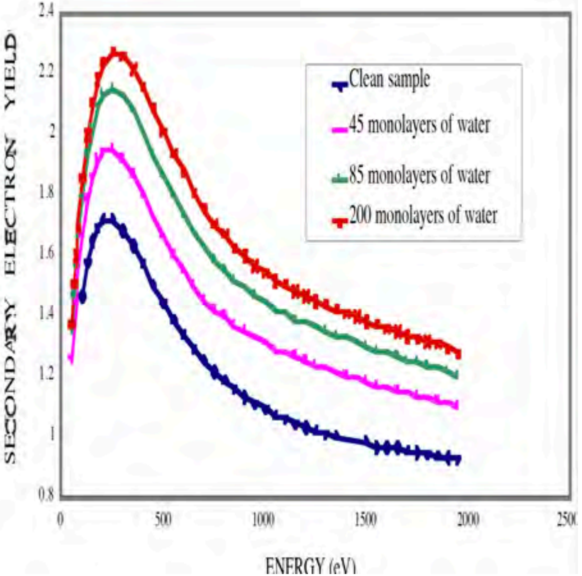
Kuzucan et al., J. Vac. Sci. Technol. A (2012)

Ar thick layer coverage



L. Spallino, M. Angelucci and R. Cimino, Phys. Rev. Acc.& Beams 23, 063201 (2020)

H_2O thick layer coverage



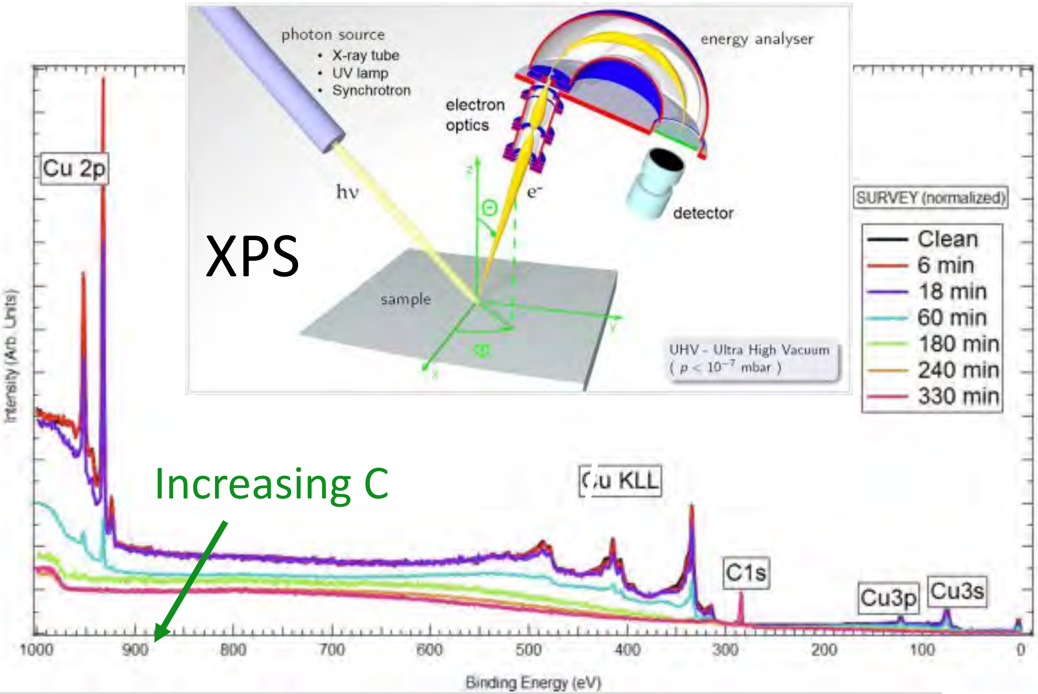
V . Baglin, et al Proceedings of EPAC 2000, Vienna, Austria

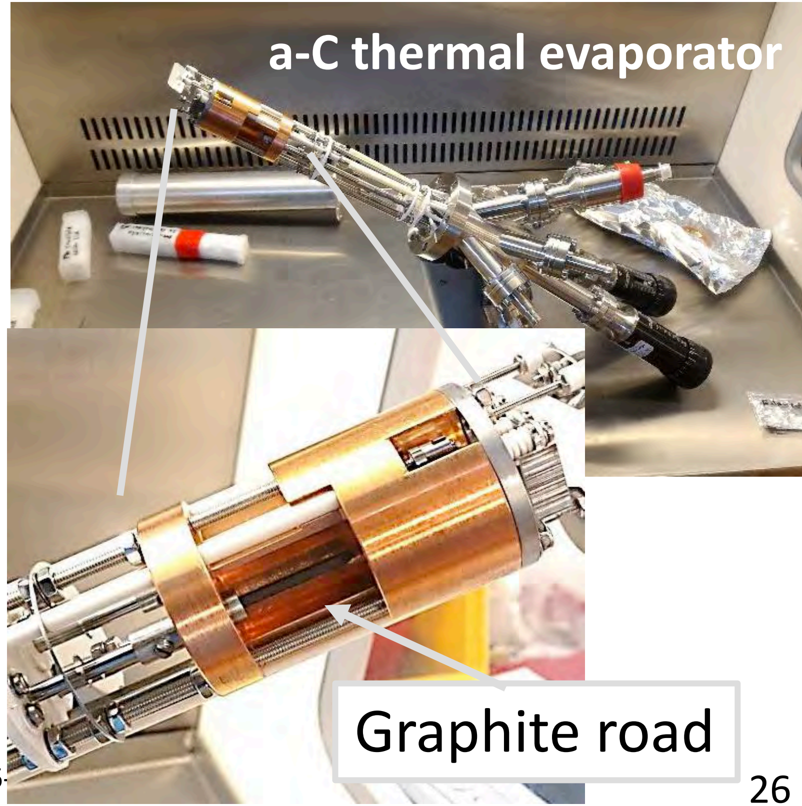
SEY is an intrinsic material property strongly sensitive to the surface composition and chemical state

Element and coverage specific

HOW A COATING MODIFY SEY? (the case of a-C on Cu)

We followed the growth of thin a-C layers on Cu with XPS to measure its thickness





M. Angelucci et. Al; Rap. Comm in Phys. Rev. Report, in print

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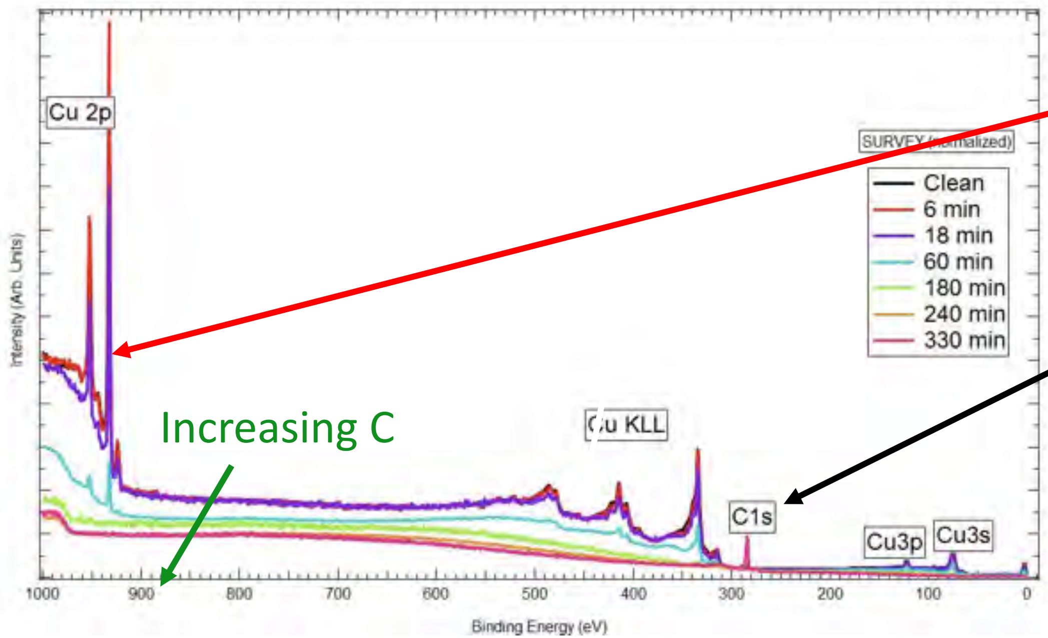

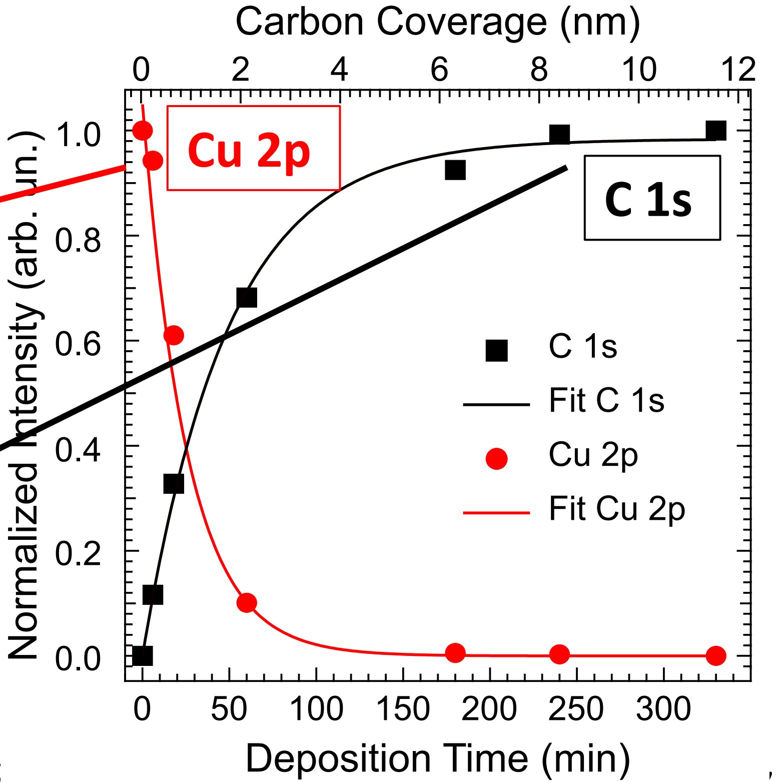

M. Angelucci et. Al; Rap. Comm in Phys. Rev. Report, in print

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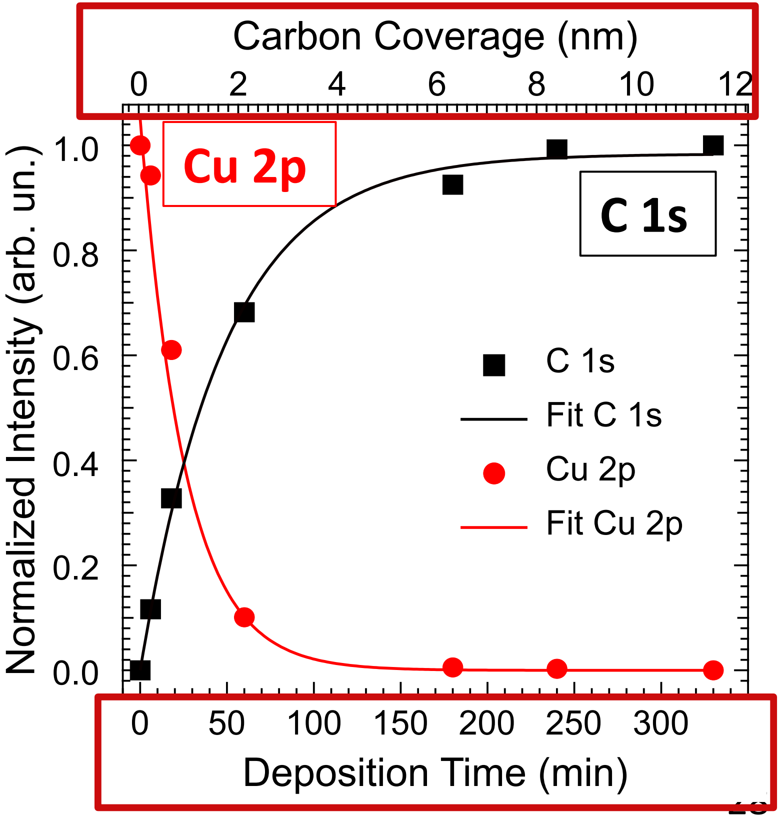
In XPS:

$$I_{Cu}^{C} = (I_{Cu,bulk}^{C})*\exp(-d/\lambda_{Cu,C})$$

$$I_{C} = I_{C,bulk}*(1-\exp(-d/\lambda_{C,C}))$$

where **d** is the unknown thickness and **λ** is the inelastic mean free path.

We can convert deposition Time in nm (±30%)



M. Angelucci et. Al; Rap. Comm in Phys. Rev. Report, in print

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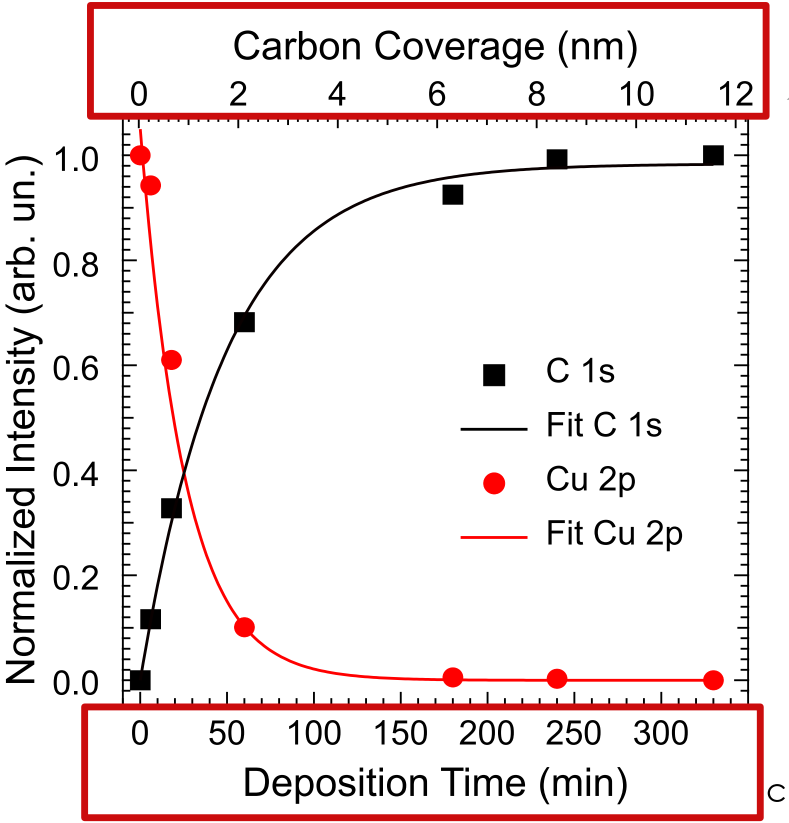


In XPS:

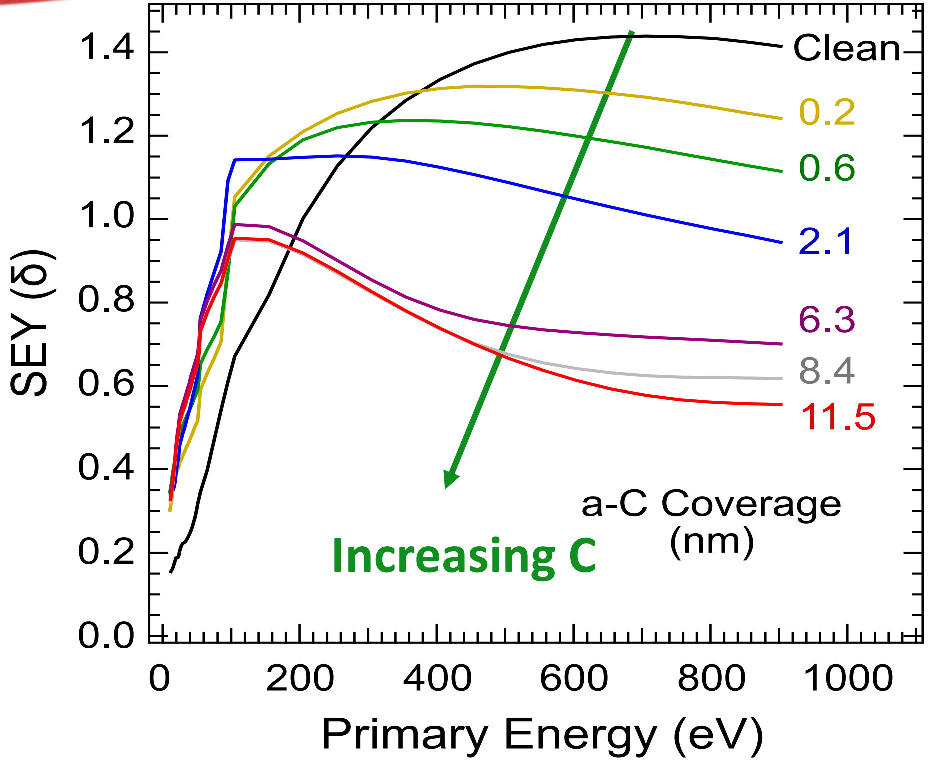
$$\begin{cases} I_{Cu}^{C} = (I_{Cu,bulk}^{C}) * \exp(-d/\lambda_{Cu,C}) \\ I_{C} = I_{C,bulk} * (1-\exp(-d/\lambda_{C,C})) \end{cases}$$

where **d** is the unknown thickness and **λ** is the inelastic mean free path.

We can convert deposition Time in nm

M. Angelucci et. Al;
Rap. Comm in Phys. Rev. Report, in print

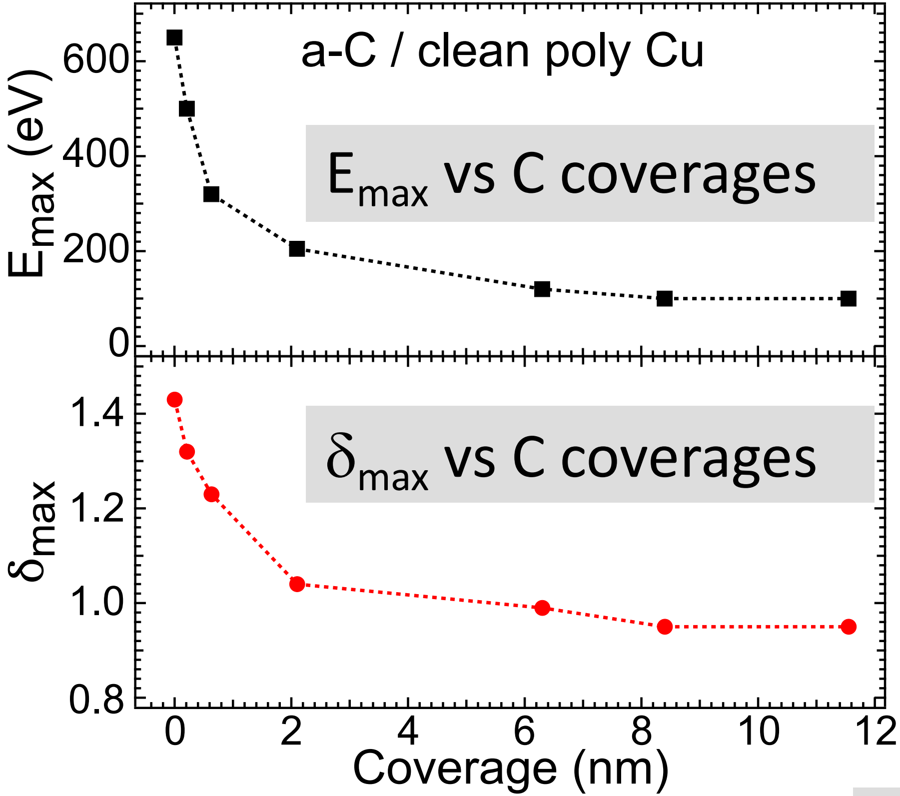
HOW A COATING MODIFY SEY? (the case of a-C on Cu)



By simultaneously follow SEY changes with a- C thickness we can measure SEY dependence on the actual a-C coverage.

M. Angelucci et. Al; Rap. Comm in Phys. Rev. Report, in print

HOW A COATING MODIFY SEY? (the case of C on Cu)



δ_{max}, E_{max} set to their (a-C) final values quite soon, while minor changes still occurs at higher doses in the very low (< ~ 20 eV) and at quite high primary energy (> ~400 eV) part.

➔ **δ_{max} (<1) and E_{max} are set after 6-8 nm of a-C**

M. Angelucci et. Al; Rap. Comm in Phys. Rev. Report, in print

CONCLUSIONS

Specific:

- LASE/LESS should be optimized also considering that they have a different **vacuum behaviour** from flat samples.
- Surprisingly, very thin coatings, of about **6-8 nm,** are enough to completely reduce clean Cu **SEY** to the one of a-C. (with marginal impact on impedance).

General:

- All new materials should be validated in a **global** approach.
- Material studies in conditions as close as possible to operational ones (preparation, Low Temperature & geometry) is mandatory.

Thank you for your attention

Thanks to the low temperature team at LNF:
M. Angelucci, A. Liedl, R. Larciprete e L. Spallino.

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